

MULTIPLE LABORATORY STUDY OF FIELD-CURED  
FLEXURAL BEAM STRENGTH RESULTS

By:

Dennis Morian, P.E.  
Quality Engineering Solutions, Inc.  
405 Water Street  
Conneaut Lake, PA  
Phone: (814) 382-0373 Fax: (814) 382-  
[dmorian@gespavements.com](mailto:dmorian@gespavements.com)

Shelley Stoffels, D.E., P.E.  
208 Sackett Building  
Department of Civil and Environmental Engineering  
The Larson Pennsylvania Transportation Institute  
The Pennsylvania State University  
University Park, PA 16802  
Phone: (814) 865-7254  
[sms26@engr.psu.edu](mailto:sms26@engr.psu.edu)

Joe Reiter  
Quality Engineering Solutions, Inc.  
405 Water Street  
Conneaut Lake, PA  
Phone: (814) 382-0373 Fax: (814) 382-  
[dmorian@gespavements.com](mailto:dmorian@gespavements.com)

Robert A. Prisby  
4814 Wheaton Drive  
Pittsburgh, PA 15236  
Phone: 412-736-9433  
[R.prisby@comcast.net](mailto:R.prisby@comcast.net)

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## INTRODUCTION

The uniformity of concrete material properties, particularly strength, is important to the performance of concrete infrastructure elements, and in particular airfield pavements. Since airfield pavement design methods rely on assumptions about concrete flexural strength as a primary level input, it is vital that the actual in-place concrete comply with these assumptions. In addition, to achieve consistent performance and avoid random performance problems associated with variation in the actual concrete placed, it is important that the material used be uniform in strength and other properties directly related to performance. Consequently, the airfield industry has relied upon flexural strength testing as the means for specifying and accepting airfield concrete, as discussed by Rapol [1].

However, far too often, variability in test results is encountered in the course of trying to complete projects. Reported flexural strength test results frequently exhibit excessive variability, and since there are numerous potential sources for this variability, disputes arise and resolution processes are necessary to close out project payment. Even then, there may be lingering questions about the compliance of the strength and uniformity of the concrete included in the work that cannot reasonably be definitively answered. Contractors may endure payment penalties as the result of sample molding, handling and testing not directly under their control, rather than as a result of concrete production, which is directly under their control. Consequently, this can be a significant issue in the airfield and other infrastructure industries that utilize flexural strength requirements to control work.

The problem associated with the use of flexural strength testing is that while defined testing procedures and related precision statement information are available for laboratory controlled specimens, no documented attempt to measure the impact and determine a precision statement for field-cured concrete flexural specimens exists. There are several potential sources of variability, and perhaps error, which can show up in reported flexural strength results. Foremost among these are potential variability in molding of test specimens, initial curing methods, transporting to a final curing facility, and the actual testing of the samples. Included in this list of potential problem areas are both mechanical and human factors. Procedural practices and errors may indeed play a large part in the derivation of unacceptable flexural strength test results, even if there is no real strength and variability problem with the actual concrete in the placement. Examples may include individual practices in molding and testing specimens. Even though specific molding procedures are required of ACI certified technicians, it is known that individual practices can affect results. Similarly, even though a specific range of loading rate is specified in the testing procedure, it is known that this portion of the testing process is often violated to speed up the testing process, and increase productivity. Further, the care exercised in handling and transporting flexural beam specimens can have a major impact on whether sample specimens are damaged prior to testing. Likewise, care in insuring that adequate curing procedures are followed can result in unacceptable test results.

The objective of this study is to provide some quantification of the collective impact of these sources of potential variability by generating field-cured flexural beam samples and test results within the parameters of a controlled test plan. This will lead to the determination of a precision statement for multiple field-cured flexural strength specimens, as determined from inter-

laboratory testing from a single concrete batch. This project was sponsored by the Innovative Pavement Research Foundation (IPRF). The Request for Proposal document indicated that one round of testing of a single concrete batch by multiple laboratories should be conducted, with potential testing of additional concrete batches to be considered based on the results from the first batch. As the additional work had not been completed in time for inclusion, this document is limited to a discussion of the results from the first batch. The focus of this first batch was to verify whether the variation currently reflected in the P 501 specification could be achieved if tight control of the sample molding, curing, and testing processes were maintained.

## LITERATURE REVIEW

The literature review phase extensively examined the reported potential causes of variability in flexural strength test results, particularly from the work of Greer [2, 3], Wright [4] and Carrasquillo [5]. Many factors were identified which could affect flexural strength test results. These include material factors, field factors and testing parameters.

Conclusions from the literature indicate the following three items are important field factors which contribute to flexural beam test result variability. Most of the variability factors identified for concrete flexural beams have been found to result in a lower identified strength in the test specimen.

- Specimen preparation/consolidation
- Initial cure deficiencies (temperatures)
- Rough handling/transportation

The following three additional factors relate to the testing process itself. It is believed that these three factors have been addressed within the existing precision statement for laboratory specimens.

- Specimen surface drying prior to testing
- Rate of loading deviations
- Pre-loading gap determination and correction

A number of material factors were indicated in the literature to increase flexural beam variability. These factors include increases in nominal maximum size of coarse aggregate and increased quantity of coarse aggregate. These factors were controlled by obtaining all beams from a single batch of concrete. The flexural strength of concrete is also extremely sensitive to the moisture distribution within the specimen.

Therefore, the results of this literature review identify the first three factors as being very important in obtaining good flexural strength test results. Improved decision making regarding the quality of in-situ concrete will be possible when these factors are better quantified and understood by the parties involved in flexural beam sampling and testing. Therefore, these factors will be considered in the development of the experimental plan.

It was determined from this review to focus on specimen preparation, curing control, and handling during transportation. While these three variables have been identified as most significant in affecting flexural strength test results, the project team focused on controlling the

variables associated with molding, curing, and transporting specimens for the experiment. Every attempt was made to control all variables within acceptable and specified limits. Consequently, due to the scope of the research and limited number of concrete mixes which could be tested, the subsequent findings do not address these variables. It was not possible to do so within the constraints of this experiment.

## EXPERIMENT DESIGN

For development of the experiment design, review and full consideration was given to the relevant ASTM standards, including:

- C-31-06 *Making and Curing Concrete Test Specimens in the Field* [6],
- C-78-02 *Flexural Strength of Concrete* [7],
- C-802 *Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials* [8], and
- C-670 *Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials* [9].

There were less than ten labs AMRL certified for ASTM C78 testing within the suitable transportation circumference. In order to accommodate this, the six available certified labs were each asked to make eight beams, meeting the minimum number of six beams each required according to C-802, with the additional beams in case one of the laboratories failed to meet the requirements of the experiment.

In addition, six labs with the C78 testing capabilities, but without current AMRL certification for the test, were included, also each making eight beams, under the same assumptions. For anticipated levels of variability reported in the literature, this would enable an adequate data pool to determine if the certified and uncertified labs produced flexural strength results that were statistically different. In the event that the results were not different, the results from all labs could be pooled to achieve the recommended minimum of ten participating laboratories [8].

## TEST SPECIMEN PRODUCTION, HANDLING AND TESTING

The technicians from all participating laboratories were assembled prior to batching the concrete and reviewed an ACI training video on flexural beam casting and testing, followed by a discussion of factors the assembled technicians had witnessed which could affect test results. Variations in testing and handling identified by the technicians included: casting beams on an incline, leaving specimens uncovered and exposed to the elements during cure, early stripping to produce results in less than two days, striking specimens with hard objects such as metal hammers or reinforcing bars to remove beam forms, “tossing” of specimens into a pickup truck, and transporting of beams unprotected in the back of a pickup truck. While not all of these events witnessed by the technicians are seen frequently, actions which result in rough handling such as improper mold removal and unprotected transport were considered to be more prevalent than uncovered cure.

Concrete was batched on July 7th, 2009 in Erie Pennsylvania at the Austin/Serv-all batch plant. The concrete mix parameters are shown in Table 1. Laboratory technicians were gathered

from Pennsylvania, Ohio, and New York and had varying travel distances from 3 miles up to 140 miles. Among the labs, six were AMRL certified specifically for ASTM C78 testing and six were not. Several of the labs had additional certifications for concrete testing, but the research team used the C78 AMRL certification to determine if variation existed between the certified versus uncertified labs.

Table 1.  
Concrete Batch Parameters.

Target Strength (psi)	Type 1 Cement (lb)	#57 Limestone (lb)	Concrete Sand (lb)	Water (lb)	Air (%)	W/C Ratio	Unit Weight (lb/cu.ft.)
700	658	1700	1195	263	6	0.40	141.30

On batching day, the test batch was cast inside the concrete supplier's garage facility, Figure 1, protected from sun and direct wind. The specimens were all field-cured for two days at the site of casting. At the end of the 2 day cure, but within the 48 hours specified in the ASTM, laboratory technicians returned to the site to strip the molds and place the beams in the water bath. The specimens were subsequently cured in temperature controlled lime water baths, also inside the garage facility. A specialized enclosure was built using foam board insulation to ensure that curing conditions for the beams were kept at optimal levels even when the garage temperature fluctuated during the curing period.



Figure 1. Casting in Concrete Supplier's Garage Facility.

The technicians returned again on the 27<sup>th</sup> day after casting to pick up the specimens and transport them to their individual labs for testing. All specimens were again placed in water bath cure tanks at the individual laboratories for a minimum of 20 hours prior to testing on the 28<sup>th</sup> day. In order to utilize an adequate number of laboratories, the transport distances varied much more than would be typical on a construction project. Therefore, transportation boxes were provided to the technicians for moving the beams to their own labs. The boxes were constructed according to the advice of a contractor who has utilized this design. These boxes were constructed of 0.75-in plywood sheeting, lined with 4 mil plastic sheets, and carpet lined to pad the specimens during transportation, as shown in Figure 2. The carpet was soaked in the curing tanks before placement in the curing boxes to ensure that the beam specimens were kept moist for transportation.



Figure 2. Transportation Boxes Lined with Wet Carpet.

Details of the testing process were also collected by each laboratory and reported along with their flexure strength test results. These included loading rate, gap measurement, beam size, beam weight, moisture condition, etc. as shown on the modified laboratory data sheet in Figure 3. This report sheet was supplied to each of the twelve laboratories, and completed by their personnel.

C-78 Amplified Data Report

Lab. ID Number	Beam ID Number	(*) Beam Weight	Ambient Temperature at Time of Test	Time Between Removal from Cure & Start of Test (<20 min.)	(**) Moisture Condition (Photo)	GAP Measurement (load applying blocks)	GAP Measurement (at support blocks)	Average Width to the Nearest .05 inch	Average Depth to the nearest .05 inch	Span Length in Inches	Rate of Loading (attach chart if available)	Max. Applied Load (lbs)	MOR to nearest 5 PSI	(*) Location Of Fracture (Photo)	1 Hour Oven Dried Moisture Content of Broken Sample at 110°F ±5° (%)	Note Defects: if capped if ground if shims used Addl. Comments use reverse & identify by Beam ID #

(\*) Beam Weight: Measure to nearest 1/10 lb.

(\*\*) Moisture Condition Definitions (include photo): SD = Surface Dry SM = Surface Moist SW = Surface Wet

(\*) Location Of Fracture (include photo): Measure inches from short end of beam to bottom of fracture

Curing History:

Transportation Time (hrs/mins):

Transportation Miles:

Field Technician ID Signature

Field Technician ID Signature

Date Conducted

Date Conducted

Figure 3. Amplified Data Recording Worksheet as Supplied to Each of the Twelve Testing Laboratories.



The concrete was batched at a low water cement ratio, representative of slipform paving. However, the technicians did not complete the molding of all specimens within the time allotted in the test procedure. Each technician cast four beams first, and then subsequently cast four additional beams. As a result, some of the beams from the second batch were found to be poorly consolidated, and were not included in the final analysis. This effect was observed at the time of casting and stripping of the specimens, and the project team was aware of the problem and looked for effects in the test results. Beams with known voids or poor consolidation were marked as special beams. During marking for poor consolidation, the research team found that all beams with known voids or poor consolidation could be visually distinguished from the higher quality beams based on visible surface voids and exposed aggregate, as can be seen in Figure 4. The resulting flexural strengths from these beams were consistently and significantly lower than for the unmarked beams. Therefore, the poorly consolidated beams were all excluded from the subsequent statistical analysis.



Figure 4. Beam with Known Voids and Poor Consolidation.

## ANALYSIS OF FLEXURAL TEST RESULTS

The data submitted from the twelve laboratories were collected and summarized in the draft IPRF project report. The data were then analyzed from several perspectives, including within laboratory variation, between laboratory variation, and overall data variability. The tabulated data were converted to an entirely numerical format for statistical analysis, using data codes for non-numeric notations from the laboratory worksheets.



After excluding the poorly consolidated beams, the results from the certified and noncertified labs were found to be indistinguishable in terms of both mean and variability at the 95 percent confidence level. Therefore, an adequate number of laboratories and beams were still available for analysis. For the simplest and most consistent analysis, and to avoid any concerns about apparent elimination of outliers, only the first four beams were used from each laboratory in the final analysis, avoiding an unbalanced experiment with different numbers of beams from different laboratories, as suggested by ASTM C802 [8]. The reported flexural strength results for those beams are shown in Table 2.

Table 2.  
Flexural Strength Results for Twelve Labs, Four Beams

Laboratory	Flexural Strength, psi				Average	Within-Laboratory Variance	Within-Laboratory Standard Deviation
	a	b	c	d			
1	790	820	815	785	803	324	18
2	880	870	960	900	903	1600	40
3	820	880	935	800	859	3721	61
4	875	895	840	810	855	1444	38
5	730	781	875	805	798	3600	60
6	770	895	910	890	866	4225	65
7	770	830	880	820	825	2025	45
8	820	820	820	950	853	4225	65
9	890	895	910	890	896	81	9
10	880	900	945	920	911	784	28
11	785	835	825	960	851	5776	76
12	850	925	850	785	853	3249	57

Analysis of variance was conducted for all variables recorded in the data worksheets. Ranges of reported values for some important variables included:

- Transport distances ranged from 3.7 to 133 miles.
- Beam lengths varied from 20 to 24 inches.
- Ambient temperatures at time of testing were between 74 and 82 degrees F.
- The recorded times between removal from cure and start of test fell between 3 and 15 minutes.
- Both surface-wet and surface-moist conditions at time of test were reported.
- The reported rates of loading varied from a range of 70-210 psi/min to 700 psi/min.
- Preloading gaps from <.004 inches to .014 inches were recorded.

Within the controlled ranges for those variables maintained within this experiment, only the ambient temperature at the time of testing was found to have a significant, but small, impact on the flexural strength. All results from the first four beams were pooled for subsequent calculations.

As discussed in the literature review section, three other impact factors related to testing which were identified included specimen drying, loading rate, and preloading gap. Every attempt was made to control these factors so they would not affect the results of the flexural strength testing. While ranges for these variables were reported as noted in the bullets above, they were not found to have a statistically significant effect within these controlled ranges. The objective for this testing was identified by the IPRF as an effort to demonstrate that the control expected in the FAA specification can indeed be reasonably achieved.

## FINDINGS AND RECOMMENDATIONS

A single batch of concrete was tested according to the provisions of ASTM C78 by twelve testing laboratories. The beams were field-cured at a central location. The following parameters were calculated as per the provisions of ASTM C802, with supplemental summary statistics provided:

- The overall average flexural strength was 856 psi, with laboratories reporting values between 798 psi and 911 psi.
- Within-laboratory standard deviations varied from 9 psi to 76 psi, with an average within-laboratory standard deviation of 47 psi.
- The pooled within-laboratory variance was 2586 (psi)<sup>2</sup>.
- The variance of laboratory averages was determined to be 1292 (psi)<sup>2</sup>, and the standard deviation of laboratory averages was 36 psi.
- The between-laboratory component of variance was 646 (psi)<sup>2</sup>.

From this first project batch, the current variation assumed in the P-501 criteria was verified, and additional testing should be undertaken to support the development of the precision statement. Prior to development of a precision statement for flexural strength of field-cured beams, it is recommended that at least two additional mixes should be tested under similar conditions by the same twelve laboratories. This additional work will provide more robust support for the development of a precision statement.

It should also be noted that, from the aspect of practical application, the factors identified from the literature are significant and must be controlled in accordance with the applicable specifications. In fact, the work summarized in this study indicates that excellent control of flexural strength specimens are required to prevent unwarranted variability from appearing in the test results. As previously discussed, there are many potential points in the sample molding, curing, and testing processes to introduce variability if strict adherence to procedures is not accomplished.

## REFERENCES

1. Rapol, Jeffrey, *Engineering Brief no. 56 Development of Revised Acceptance Criteria for Item P-401 and Item P-501*, FAA, March 11, 1998.
2. Greer, Wilbur Charles, *Evaluation of Strength Tests and Acceptance of Concrete Pavements*, Pub. No. FHWA-RD-89-208, April 1989, pp 375-383.

3. Greer, Wilbur Charles, *Factors Affecting Mix Design, Quality Control and Acceptance Testing for Airport Concrete Pavements*, pp. 8-13.
4. Wright, P.J.F., *The effect of the method of test on the flexural strength of concrete*, Road Research Laboratory, Concrete Research, October 1952.
5. Carrasquillo, P.M. and Carrasquillo, R.L., *Improved Concrete Quality Control Procedures Including Third Point Loading*, FHWA/TX-88+1119-1F, November 1987.
6. ASTM C-31-06, *Making and Curing Concrete Test Specimens in the Field*, ASTM International, West Conshokocken, PA.
7. ASTM C-78-02, *Flexural Strength of Concrete* (Using Simple Beam with Third-Point Loading), ASTM International, West Conshokocken, PA.
8. ASTM C-802, *Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials*, ASTM International, West Conshokocken, PA.
9. ASTM C-670, *Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials*, ASTM International, West Conshokocken, PA.